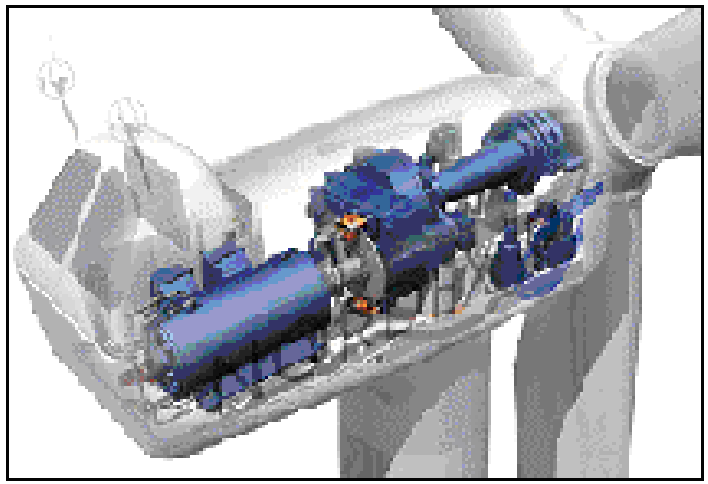
Introduction to ANSI/AGMA/AWEA 6006-A03, Standard for Design and Specification of Gearboxes for Wind Turbines

NREL/DOE Wind Turbine Drivetrain Research



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AGMA/NREL Wind Turbine Drivetrain Seminar
The Omni Interlocken Resort – Broomfield, CO – April 26—27, 2004

DOE/NREL Drivetrain Research

- Support for ***ANSI/AGMA/AWEA 6006-A03***
- Low Wind Speed Turbine Project
  - WindPACT Drivetrain Studies
- Dynamometer development and testing

Gear Standards History

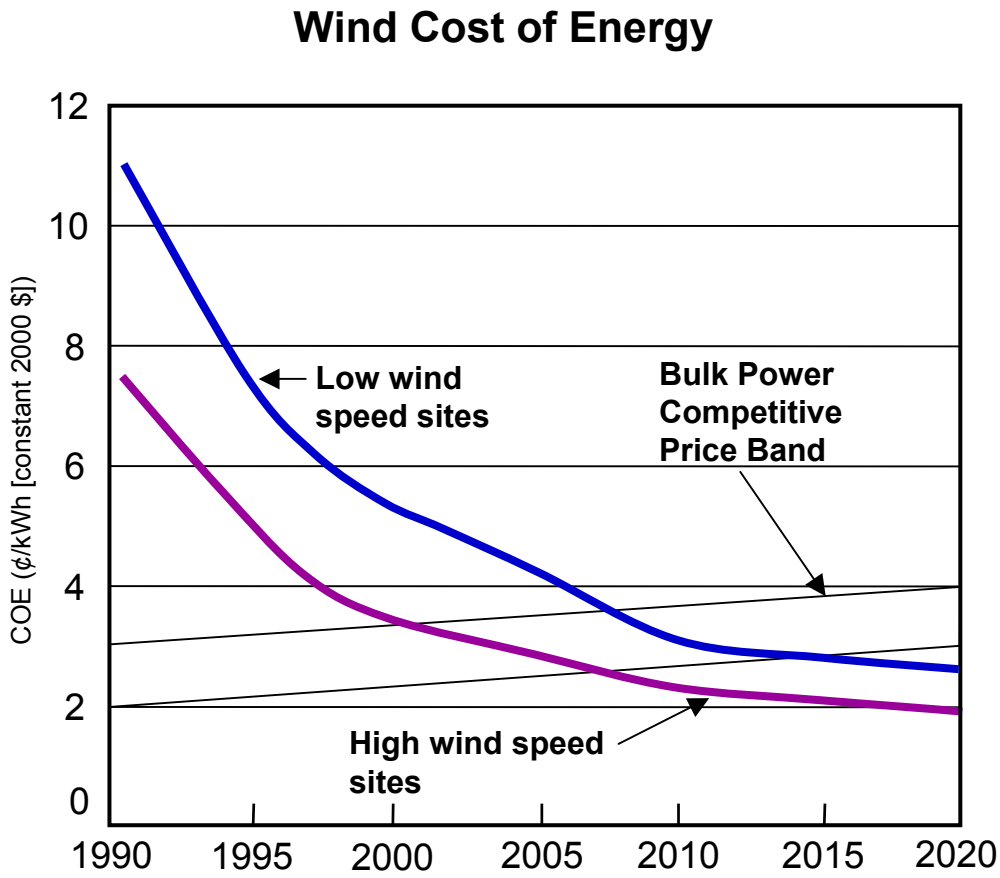
- Gearboxes were viewed as mature technology-1980'S
- Drivetrain/gearbox research was not within the scope of wind turbine R&D.
- Widespread field failures plagued the industry.
- Systems engineering problem:
  - Higher loads – torque excursions, braking, transient.
  - Noise
  - Vibration
  - Service – lubrication, PM, etc

- The need to develop guidelines recognized – 1991
- GEARTECH was contracted by NREL to write:
  Errichello, R., and Muller, J. "Application Requirements for Wind Turbine Gearboxes" NREL/TP-442-7076,, September, 1994
- Became the draft text for ***ANSI/AGMA/AWEA 6006-A03***.
- AGMA/AWEA Gearbox Committee formed in 1993
- NREL/AWEA co-sponsorship with AGMA

Low Wind Speed Technology

- Current Situation
  - Wind energy viable at higher wind speed sites (Class 6 – avg. 15 mph @ 10m)
  - Subsidies important
  - Far from load centers
- New Focus
  - Extend range of economically competitive sites to Class 4.

  (Class 4 – avg. 13 mph @ 10m)
  - 20x land area
  - Diminish need for subsidy
  - Closer to load centers



Cost of Energy Reductions

Three (technical) ways to reduce COE:

- Reduce Installed Capital Cost (ICC)
- Reduce Operations and Maintenance Cost (AOE)
- Increase Annual Energy Production (AEP)

$$COE = \frac{(FCR \times ICC)}{AEP} + AOE$$

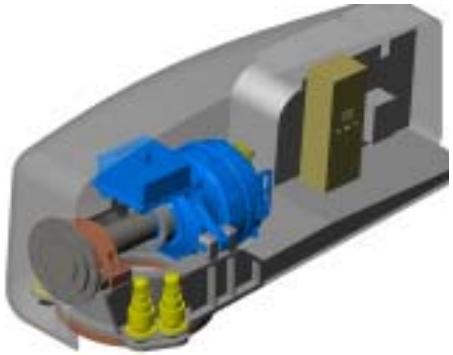
Utility Scale Turbine Cost Reduction Potential

Technology Improvements	Estimated COE Improvement
• **Advanced rotors and controls –** (flexible, low-solidity, higher speed, hybrid carbon-glass and advanced and innovative designs)	**-15% ± 7%**
• **Advanced drive train concepts -** (Hybrid drive trains with low-speed PM generators and other innovative designs including reduced cost PE)	**-10% ± 7%**
• **New tower concepts** - (taller, modular, field assembled, load feedback control)	**-2% ± 5%**
• **Improved availability and reduced losses** - (better controls, siting and improved availability)	**-5% ± 3%**
• **Manufacturing improvements** - (new manufacturing methods, volume production and learning effects)	**-7% ± 3%**
• **Region and site tailored designs** (tailoring of larger 100MW wind farm turbine designs to unique sites)	**-5% ± 2%**

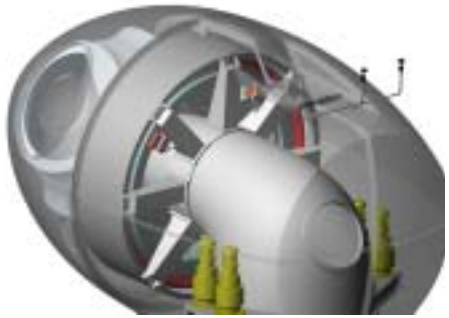
WindPACT Drive Train Studies
(Wind Partnerships for Advanced Component Technology)
http://www.nrel.gov/wind/windpact/

- Study Objectives: Identify drive train configuration(s) with the potential to reduce the cost of energy from wind turbine systems.
  - Perform preliminary design studies of several innovative drive train concepts
  - Design, fabricate, and test a prototype of the most promising concept.
- Two companies selected under competitive solicitation.
  - Global Energy Concepts
  - Northern Power Systems
- Total funding $11.76M 100% DOE.

WindPACT - Drive Train Weight Comparison



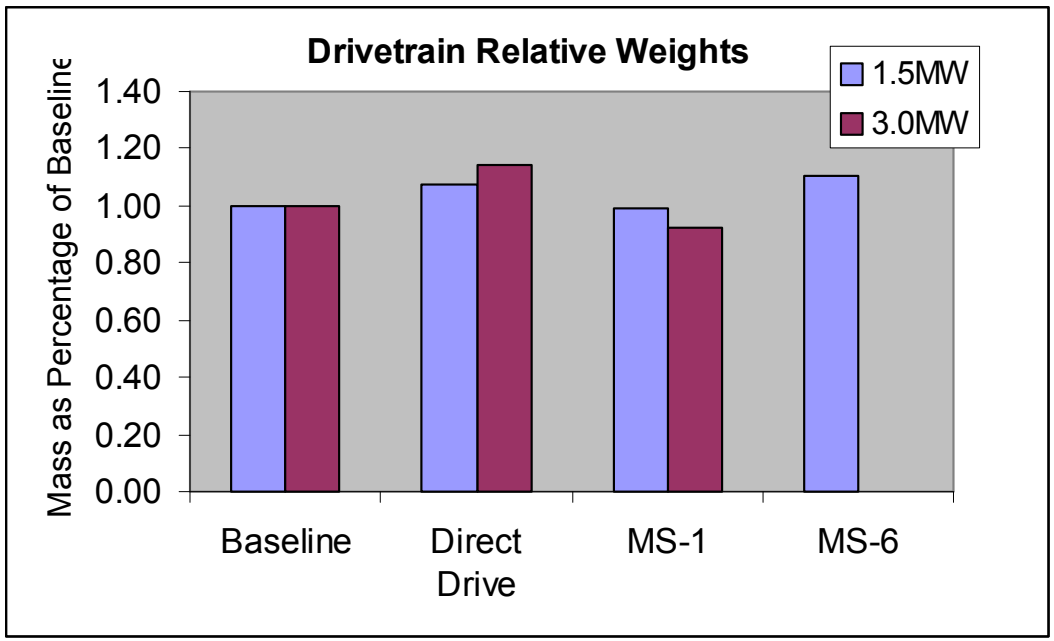
Baseline



Direct Drive-
Permanent Magnet

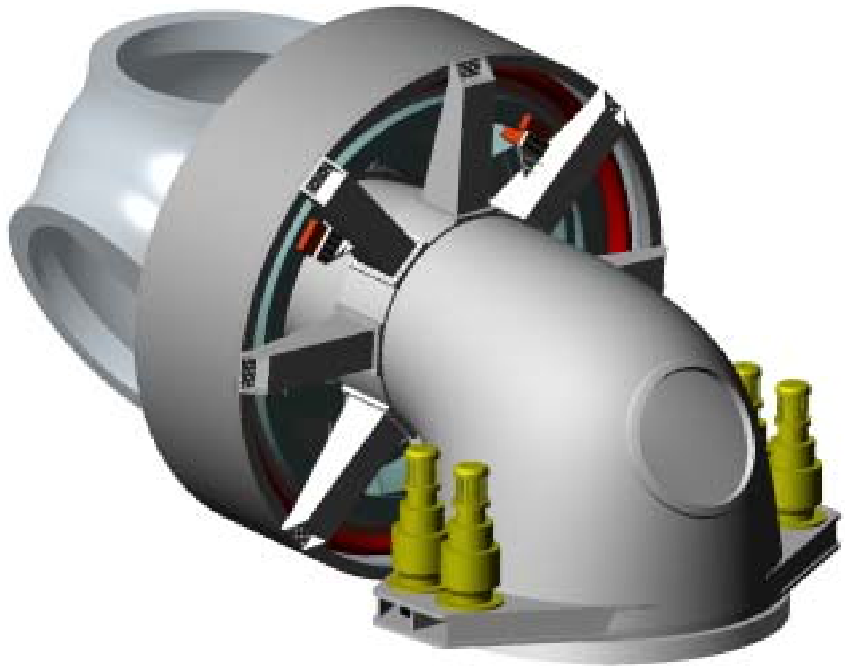
MS-1 Single Stage
Medium Speed

MS-6 –Multiple
Generator



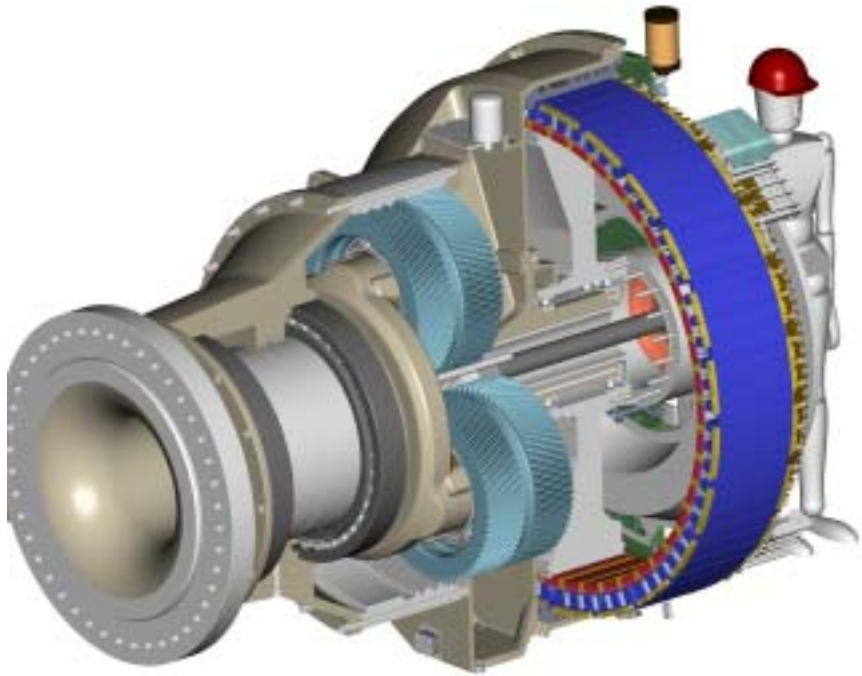
Northern Power Systems WindPACT Project Status

- 1.5 MW Direct Drive Permanent Magnet Generator
- Power Conversion Using Standard AC-DC-AC Current Link with PWM Switching
- Fabrication Underway
- Unit to Be Delivered for Testing Mid Summer 2004
- Primary Partner – GD Electric Boat
- COE Claims: Lower O&M, higher AEP due to efficiency, reduced ICC(assumes downward magnet cost trends continue)



Global Energy Concepts WindPACT Project Status

- 1.5 MW Single Stage Gearbox with Low Speed PM Generator
- Simplified Power Conversion Using SCRs and Staggered Phasing to Improve Output Quality
- Power Correction To Take Place at Wind Farm Level
- Fabrication Underway
- Unit to Be Delivered for Testing – April 2004
- Primary Partner – Kaman Electrodynamics



http://www.nrel.gov/publications/
Alternative Design Study Report: WindPACT Advanced Wind Turbine Drive Train Designs Study, November 1, 2000 - February 28, 2002

NREL's 2.5-MW Dynamometer Development

- In 1994, the AWEA/US wind industry requested a facility to conduct testing on a new generation of 500-kW+ machines.
- NREL began the development of a dynamometer test facility in 1997.
- The NREL 2.5-MW dynamometer was commissioned in August 1999.
- Purpose: To conduct laboratory tests on wind turbine drivetrains that are difficult or impossible to perform in the field.

DRIVETRAIN TESTING

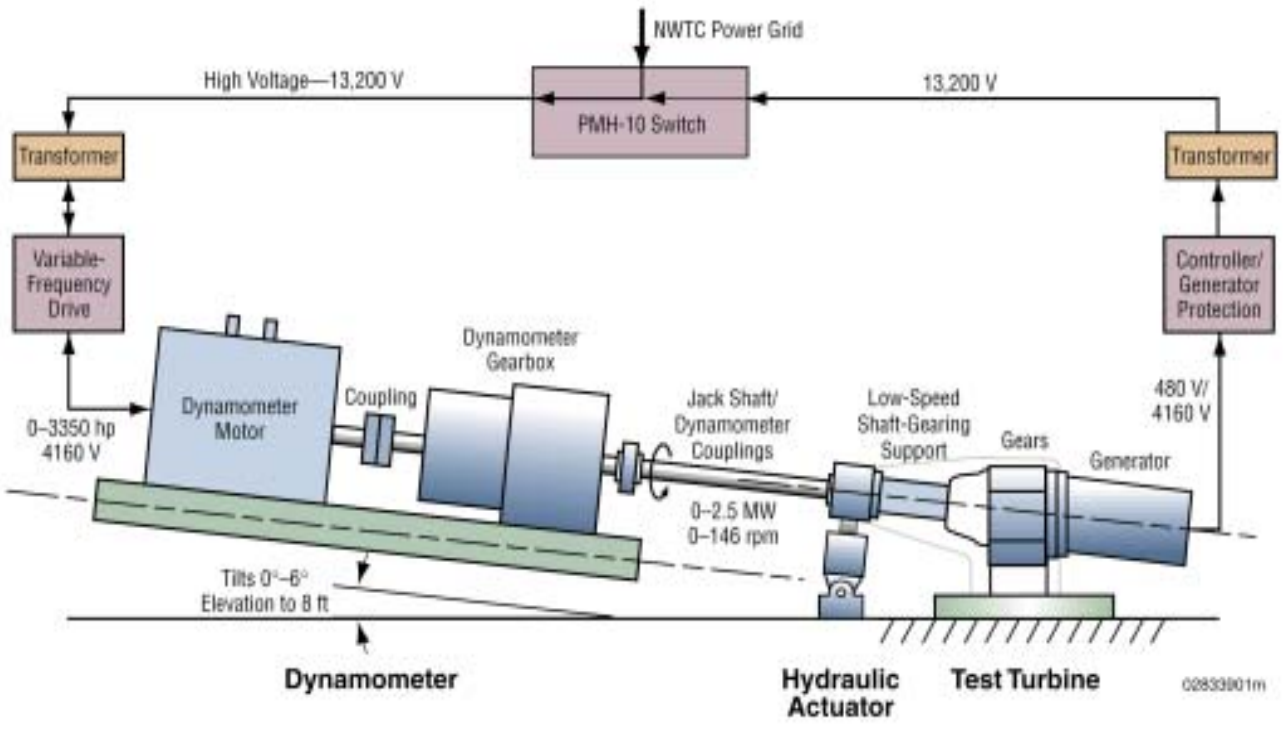
- NREL dynamometer R&D testing, Slow change-out
- Full system verification
- Gearbox- radial shaft loading possible
- Generator testing
- Power converter and control system.
- Ancillary equipment brakes, lubrication, nacelle temperature.

GEARBOX TESTING

- Most testing conducted at the gearbox suppliers.
- Wear-in testing, lubrication function, contact pattern, thermal verification, and prototype endurance testing.
- Rapid change-out
- Validation and acceptance testing.
- New configurations difficult.

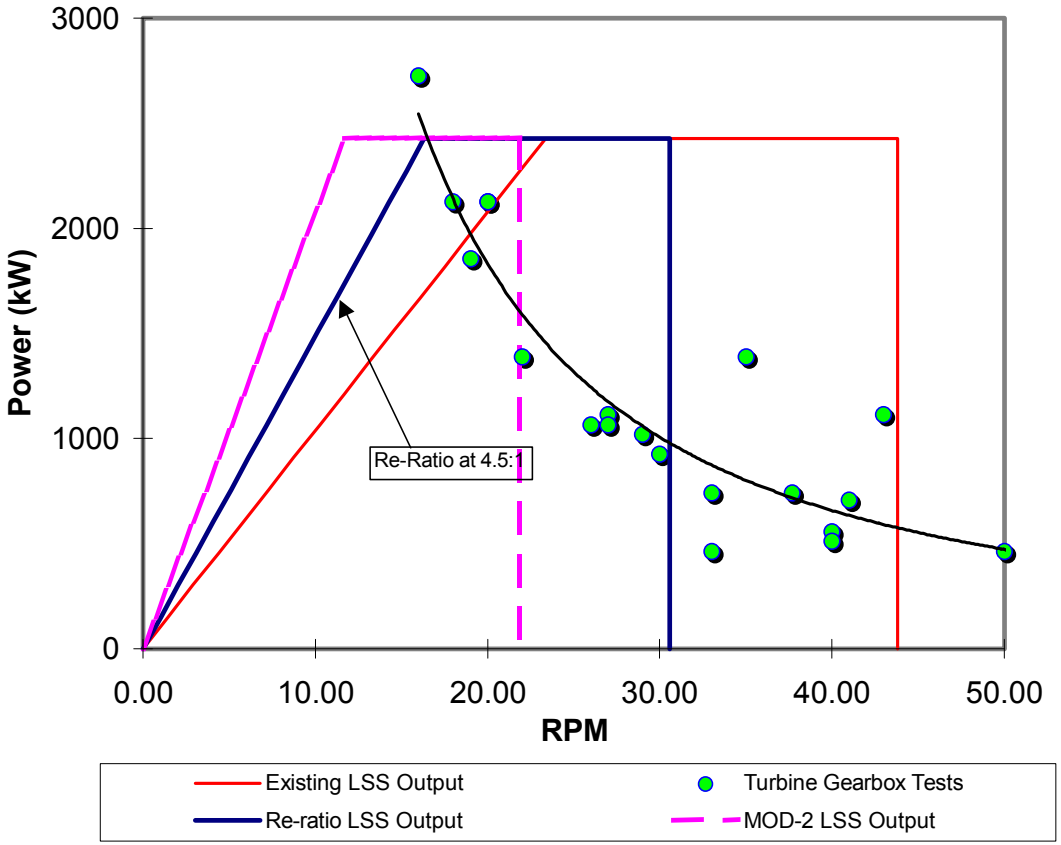
Dynamometer Background/Specifications

- 2.5 MW rated power capacity -power regeneration at 480/575or 4160 volts.
- Torque range 0 - 1.62 million N-m (9.44 million in-lb).
- Speed range from 0 - 2250 RPM
- 488 kN (110 kip) force capacity for dynamic shaft bending with servo-hydraulic controls.
- Fully automated SCADA torque/speed controls



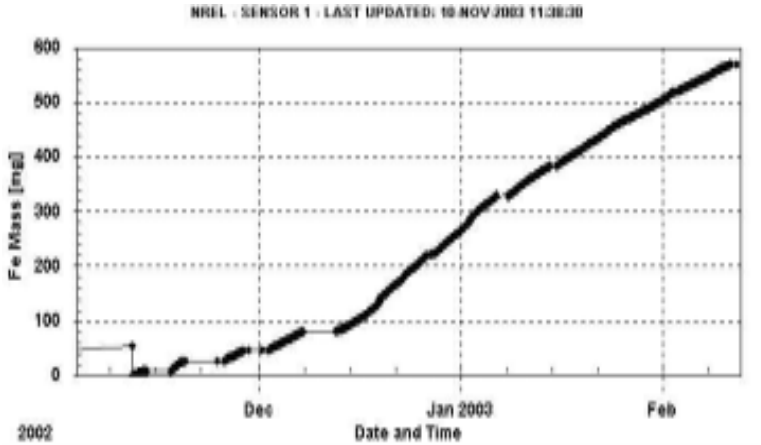
2004

Dynamometer Operating Envelope

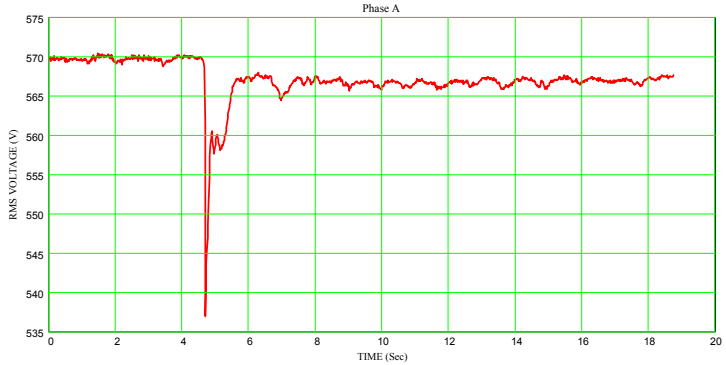


- Current Facility Limited at 9.44MM in-lbs @ 23-RPM.
- New upgrade in increase capability – 13.5MM in-lbs @ 16-RPM
- New HS gear set will enable full-power tests on 2.5-MW drives.

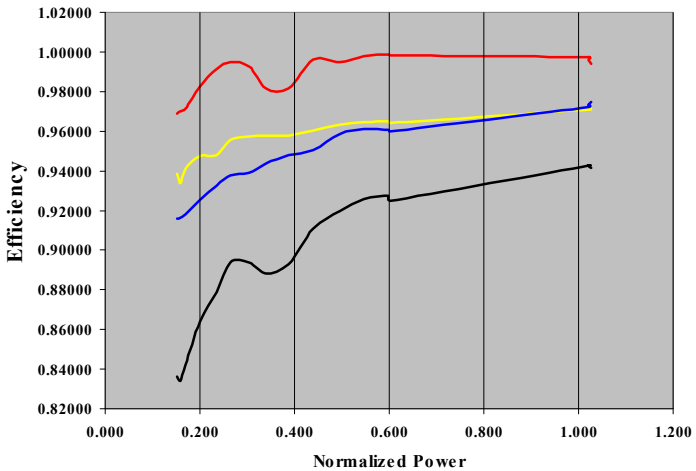
Dynamometer Testing at NREL



Lubrication and Health Monitoring, Stress wave energy



Power Quality Verification Controls and Transient Response

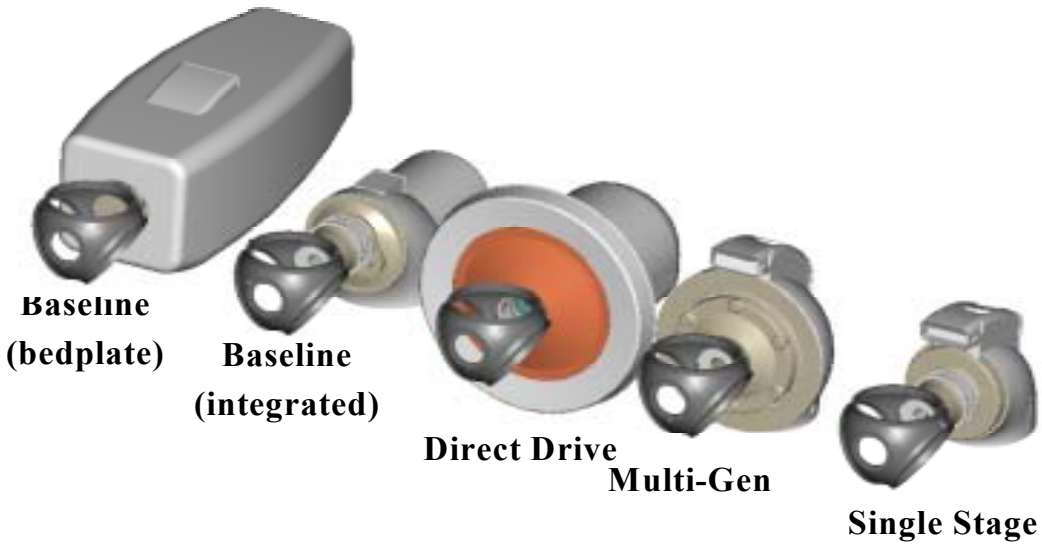


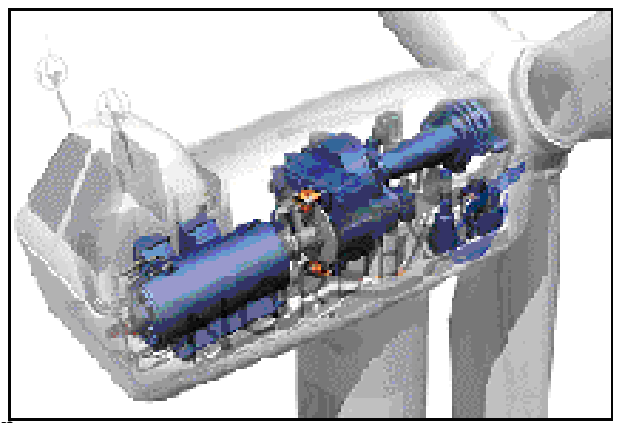
System and Component Efficiencies, System Thermal Verification

Design-life Equivalent Endurance Testing

Future Strategies for Drivetrains

- Invest in technologies that show promise for lower COE
  - Low Wind Speed Turbine project
  - *http://www.nrel.gov/wind/about_lowspeed.html*
  - Onshore and Offshore.
- Develop new large turbine test facilities
- Support the development of international standards for wind turbines.





Future Plans

DOE/NREL Test Facilities

1989
FIRST BLADE TEST FACILITY IN USA

1996
INDUSTRIAL USER FACILITY TESTING FOR BLADES UP TO 37-METERS

1999
DYNAMOMETER TEST FACILITY FOR TURBINES UP TO 2.0-MW

NO LARGE TURBINE TEST FACILITIES EXIST IN THE USA

Wind Turbine Size

2006
2500-kW
45-METER BLADES

2009
5000-kW
60-METER BLADES

2012
7000-kW
70-METER BLADES

Average Commercial Turbine Sizes

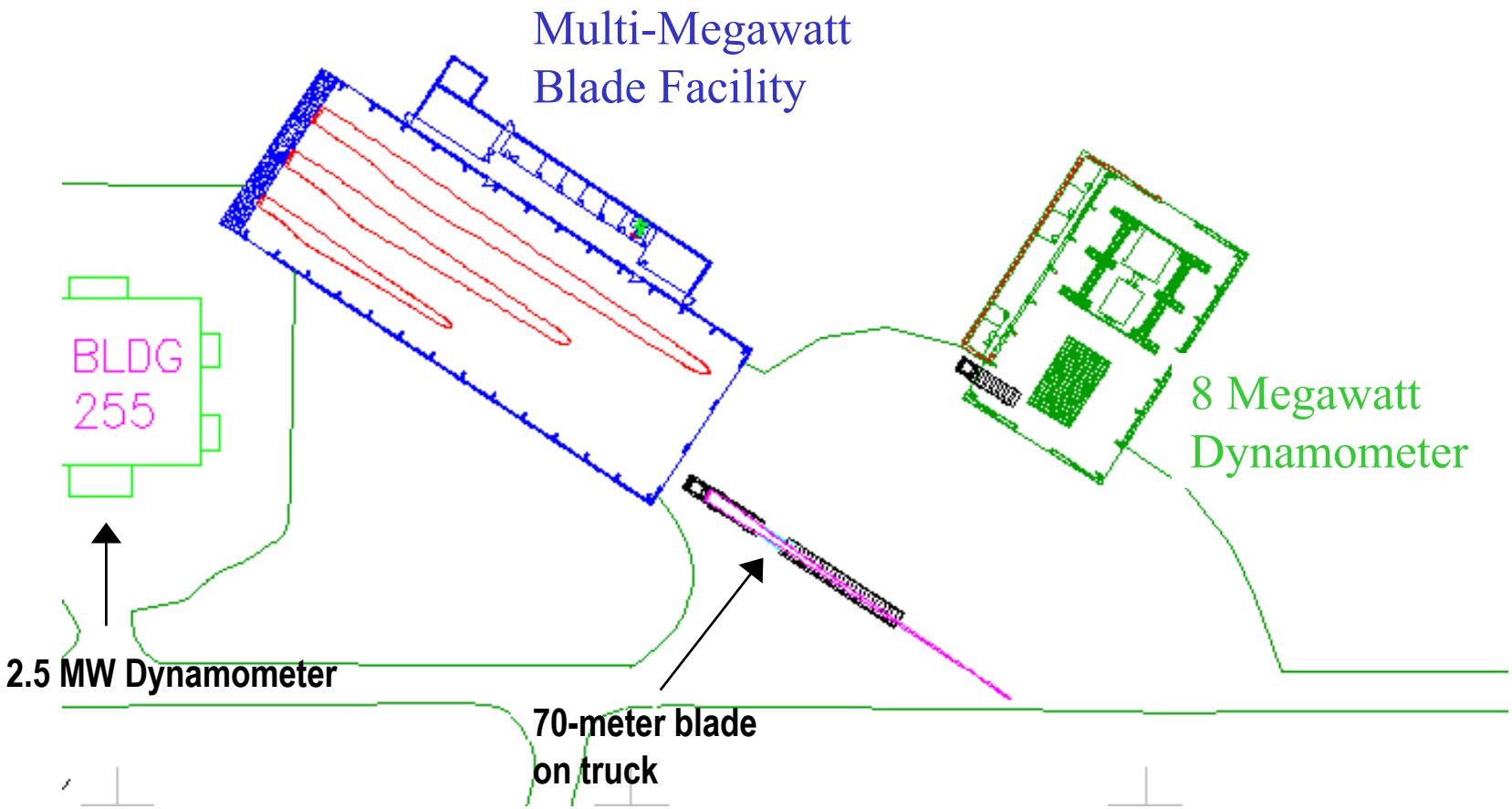
1989
100-kW
9-METER BLADES

1996
500-kW
19-METER BLADES

1999
750-kW
24-METER BLADES

2003
1500-kW
37-METER BLADES

Layout of Proposed Multi-Megawatt Test Facilities



Tour of National Wind Technology Center

AGMA/NREL Wind Turbine Drivetrain Seminar
The Omni Interlocken Resort – Broomfield, CO – April 26—27, 2004

Current Test Program
Clipper DGD-1

- Clipper Windpower DGD-1 Drive Installed March 2003.
- Unique Prototype eight-generator 1.5-MW Drivetrain Topology.
- Mechanical test phases completed.
  - Lube system verification, functional, thermal.
  - Verified smooth mechanical operation.
- Electrical system start-up problems resolved.
  - Field control system, load bank, capacitor circuit, converter software.
- New method to determine proper tooth modifications: Measured load intensity variations on HS Pinion with strain gages.
- Achieved endurance load, full-speed operation. 30% over rated power.

Clipper WINDPOWER

Blade Test Video

LWST Resonance Blade Fatigue Test System

- New system uses 1/3 the energy
- New system can test the full-blade length.
- Resonance system scales to large blades.
- Patent application filed by NREL – national patents pending

Høvsøre Test Facility at Risø

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